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On the applicability of fair and adaptive data dissemination in traffic information systems

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ABSTRACT

Vehicular Ad hoc Networks (VANETs) are expected to serve as support to the development of not only safety applications but also information-rich applications that disseminate relevant data to vehicles. Due to the continuous collection, processing, and dissemination of data, one crucial requirement is the efficient use of the available bandwidth. Firstly, the rate of message transmissions must be properly controlled in order to limit the amount of data inserted into the network. Secondly, messages must be carefully selected to maximize the *utility* (benefit) gain of vehicles in the neighborhood. We argue that such selection must aim at a *fair* distribution of data utility, given the possible conflicting data interests among vehicles.

In this work, we propose a data dissemination protocol for VANETs that distributes data utility fairly over vehicles while adaptively controlling the network load. The protocol relies only on local knowledge to achieve fairness with concepts of Nash Bargaining from game theory. We show the applicability of the protocol by giving example of utility functions for two Traffic Information Systems (TIS) applications: (i) parking-related and (ii) traffic information applications. The protocol is validated with both real-world experiments and simulations of realistic large-scale networks. The results show that our protocol presents a higher fairness index and yet it maintains a high level of bandwidth utilization efficiency compared to other approaches.

1. Introduction

With Vehicular Ad hoc Networks (VANETs), numerous applications are expected to aid drivers not only with safety-related information but also with general traffic data such as the current traffic condition and parking information. In particular, Traffic Information Systems (TIS) form an important category of non-safety applications that aim to enhance passenger comfort and traffic efficiency [1]. The information produced by these systems is generally more frequent but also valid for a longer period of time compared to emergency data. This characteristic poses specific requirements and challenges for the design of data dissemination protocols.

Due to the continuous collection, processing, and dissemination of data, one crucial requirement in TIS is the *efficient* use of the available bandwidth. The amount of data collected can increase quickly even with aggregation algorithms. In addition, the time window for data exchange can be very limited due to the rapidly changing road environment. Firstly, the rate of message transmissions must be properly controlled in order to limit the

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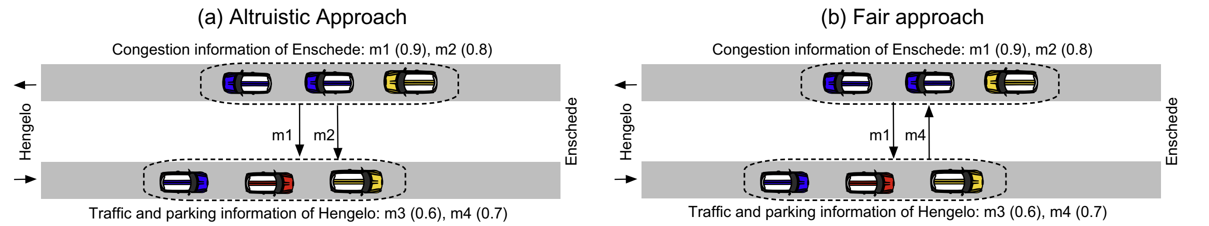

Fig. 1. Motivation for a *fair* data selection. In (a), only vehicles heading to the city of Enschede receive information, namely, congestion information about Enschede. A fair approach in (b) leads to a more even distribution of utility, providing traffic awareness to vehicles in both road directions.

amount of data inserted into the network. Secondly, as a consequence, messages must be carefully selected by means of data selection mechanisms in order to maximize the *utility* (benefit) gain of vehicles in the neighborhood. We argue that such mechanisms must aim at a *fair* distribution of data utility, given the possible conflicting data interests among vehicles. As exemplified in Fig. 1, vehicles moving in opposite directions are potentially interested in each other's data, since a group of vehicles in one direction holds data related to the destination of vehicles in the opposite direction. If we consider a hypothetical situation where there is only enough time or available bandwidth for the exchange of two messages, a fair approach would choose messages m_1 and m_4, thereby providing a gain of 0.9 of utility to vehicles moving to Enschede and a gain of 0.7 to vehicles moving to Hengelo. In contrast, an Altruistic-based approach [2] that maximizes the total utility gained by all vehicles in the neighborhood would choose m_1 and m_2, thereby leaving vehicles in one direction with no information about their destination.

The novelty of this work lies in addressing both problems of controlling the network load and selecting data in a road environment where vehicles have conflict of data interests. We present a broadcast-based data dissemination protocol that distributes data utility fairly over vehicles while adaptively controlling the network load, which we refer to as FairAD: *Fair* and *A*daptive data *D*issemination. The protocol relies only on local knowledge to achieve fairness with concepts of Nash Bargaining from game theory. FairAD is a result of combining two independent lines of work, namely, the data selection mechanisms discussed in [3,4] and the adaptive beaconing control proposed in [5,6]. In [7], we have shown the capability of FairAD to control the network load while selecting messages with high utility and fairness to the neighborhood. This work complements [7] with the following contributions:

– Demonstration of the applicability of FairAD by giving example of utility functions for two TIS applications: (i) parking-related and (ii) traffic information applications. We additionally study the effects when both applications are considered simultaneously in our performance evaluation.
– Real-world experiments with two vehicles moving in opposite directions on a highway at high speeds. We validate the behavior of FairAD and other data selection approaches and study aspects such as the average connectivity time, transmission range achieved, packet loss and throughput.
– Validation of FairAD and other data selection approaches with simulations in large-scale networks. In particular, as urban scenario, we take a real map fragment from the Manhattan area in New York City, USA, including the shape of buildings that are used to model radio obstacles.

The remainder of this paper is organized as follows. In Section 2, we outline relevant related works and motivate the contribution of this work. Section 3 details the functioning of FairAD. In Section 4, we present example of two TIS applications along with their utility functions. The validation of FairAD is presented in Section 5. Finally, Section 6 concludes this paper.

2. Related work

One of the earliest works proposing the use of application utility for data selection is [2]. Authors focus on solving scalability issues in disseminating data in VANETs by selecting messages that maximize the total utility gained by all vehicles in the neighborhood. Differently, authors in [8] introduce a protocol that allows content to remain available in areas where vehicles are most interested in it. A detailed study of using utility to reduce the uncertainty of sensor data gathered by vehicles is presented in [9]. Similar to this work is [10], where authors consider the average system information age to maintain up-to-date state information among all nearby vehicles. In [11], a Peer-to-Peer (P2P) approach is introduced to address the problem of popular content distribution (PCD) in VANETs when a file is broadcast by roadside units (RSUs) to vehicles. Vehicles cooperate by exchanging data and complementing their missing packets. In [12], PrefCast is proposed. The protocol focuses on a preference-aware content dissemination that targets on maximizing the user's satisfaction in terms of content objects received. When a node meets neighboring users for a limited contact duration, it disseminates the set of objects that can bring possible future contacts a high utility. Although not explicitly defined in a general utility function, the Road Information Sharing Architecture (RISA) is presented in [13]. The architecture comprises a distributed approach to road condition detection and dissemination for vehicular networks. A Time-Decay Sequential Hypothesis Testing (TD-SHT) approach is used to combine event information from multiple sources to increase the belief of such events. Finally [14] presents an information dissemination function to